Parameterisation of the fundamental subgrid turbulence interactions

Maintaining resolution independent statistics for all spatial scales

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In order to simulate the global atmosphere or ocean, one explicitly resolves the large scales on a computational grid, with the unresolved subgrid interactions parametrized. If these subgrid interactions are not parametrized self-consistently, the simulations become resolution dependent.

We demonstrate a solution to this significant and long-standing problem by replicating a reference T63 two-level quasi-geostrophic simulation of the atmosphere by a T31 simulation. All parameterisation coefficients are determined in spectral space from the reference case with no arbitrary tuning parameters.

$$\boldsymbol{q}_t \equiv \partial \boldsymbol{q}/\partial t$$

Complete Time Derivative

$$\boldsymbol{q}_t^R$$

Explicitly Resolved by Grid

$$\boldsymbol{q}_t^S$$

Parameterised Subgrid Interactions

We define q_{mn}^j as the reduced potential vorticity at vertical level j of longitudinal and total wavenumbers (m,n), and state vector $\boldsymbol{q} = (q_{mn}^1, q_{mn}^2)^T$.

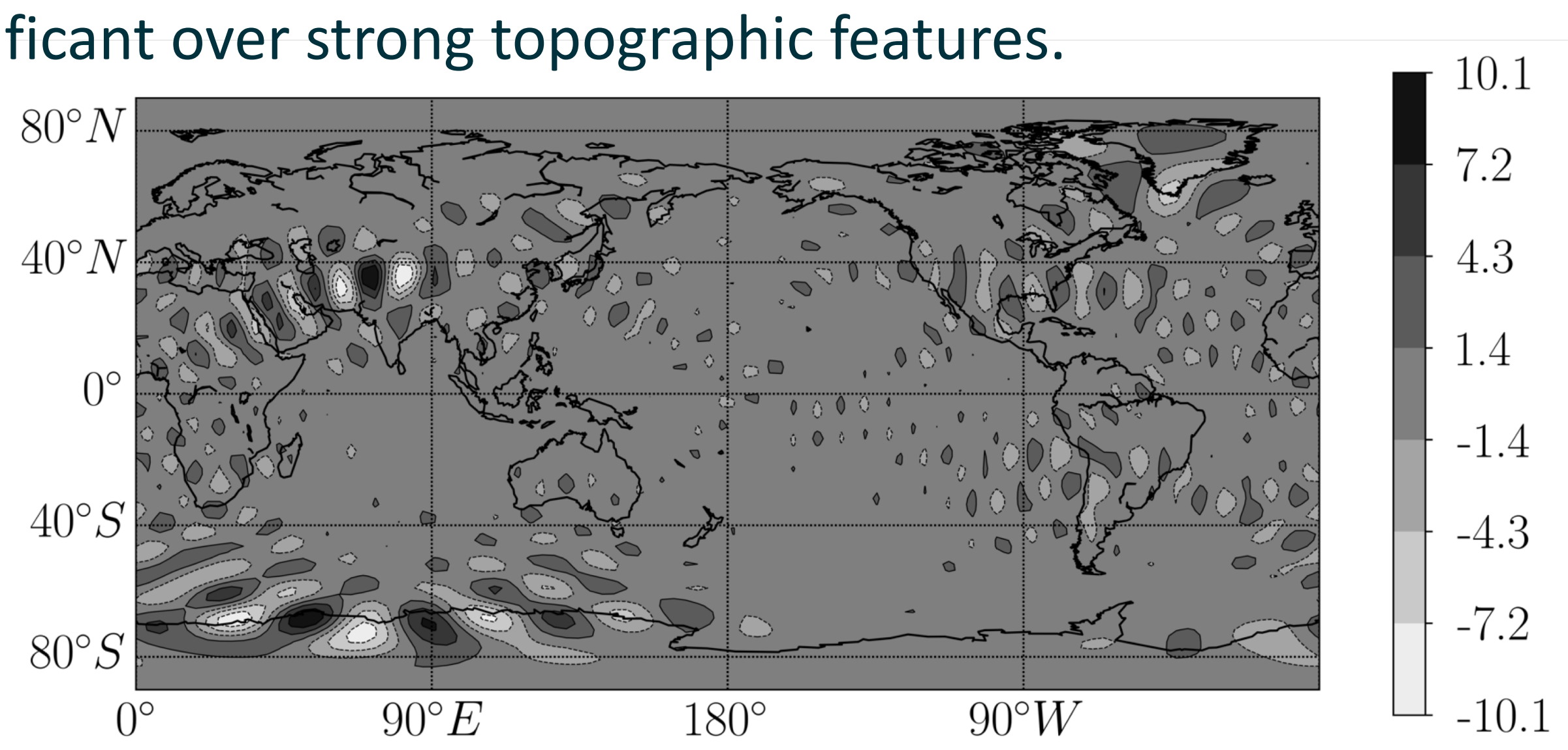
By truncating the reference simulation to lower resolution, we decompose the time derivative ($\boldsymbol{q}_t$) into its resolved ($\boldsymbol{q}_t^R$) and subgrid ($\boldsymbol{q}_t^S$) components, with the latter decomposed into fluctuating ($\widehat{\boldsymbol{q}}_t^S$) and time averaged ($\overline{\boldsymbol{q}}_t^S$) parts.

$$\overline{\boldsymbol{q}}_t^S = \boldsymbol{J} - \overline{\boldsymbol{D}}\overline{\boldsymbol{q}} + \boldsymbol{\chi h}$$

Mean Subgrid Tendency - decomposed into the following interaction classes for each wavenumber pair (m,n) using a new regression method, and illustrated in physical space as meridional accelerations at the bottom level.

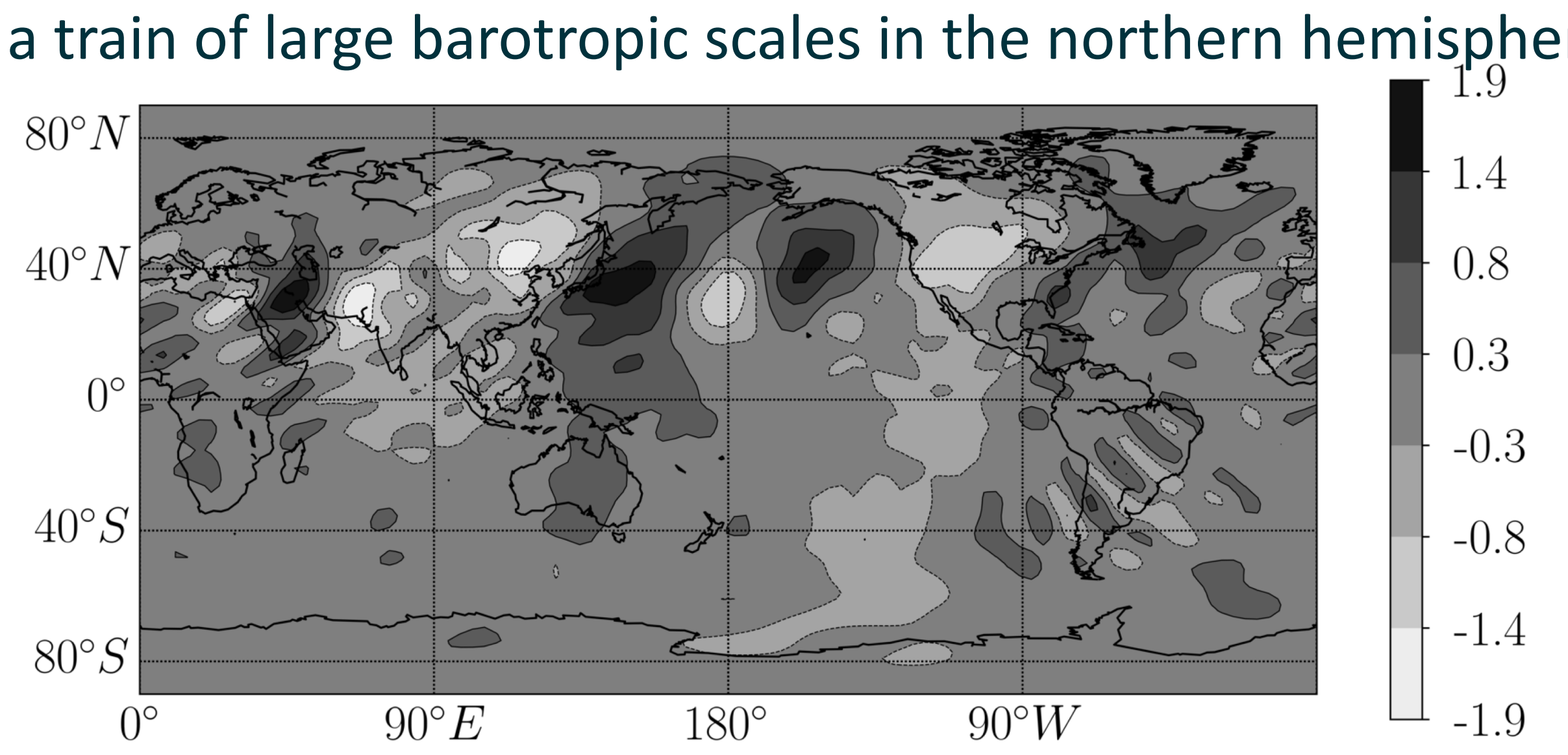
$\boldsymbol{J}$: Meanfield–Jacobian Interactions

Sum of the **Meanfield-Meanfield** and **Meanfield-Topographic** interactions, and significant over strong topographic features.



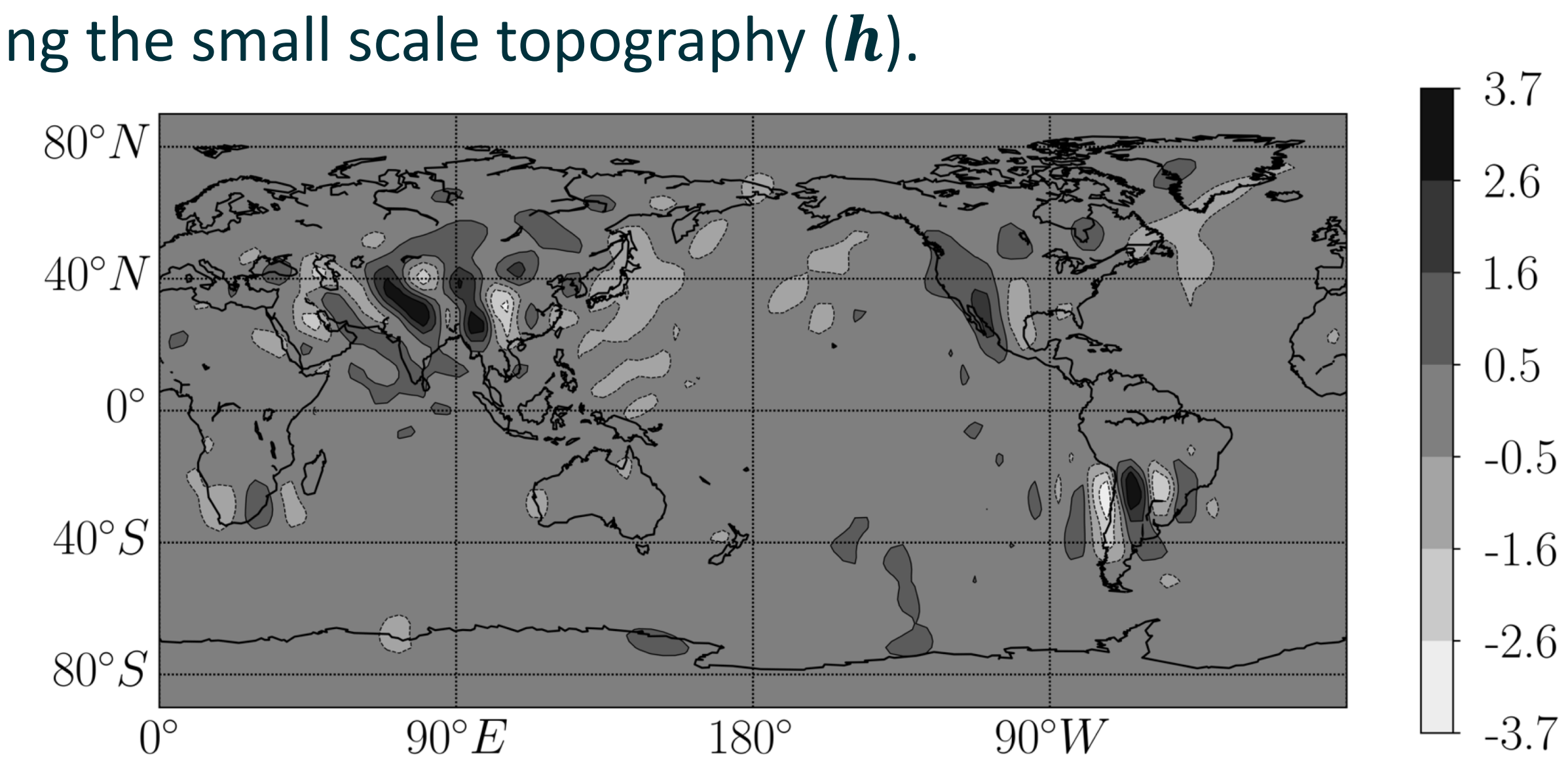
$-\overline{\boldsymbol{D}}\overline{\boldsymbol{q}}$: Eddy–Meanfield Interactions

Edd-meanfield 2×2 dissipation matrix ($\overline{\boldsymbol{D}}$) acting upon the meanfield ($\overline{\boldsymbol{q}}$), to produce a train of large barotropic scales in the northern hemisphere.



$\boldsymbol{\chi h}$: Eddy–Topographic Interactions

Eddy-topographic 2×2 matrix ($\boldsymbol{\chi}$) acting as a high pass filter preferentially amplifying the small scale topography ($\boldsymbol{h}$).

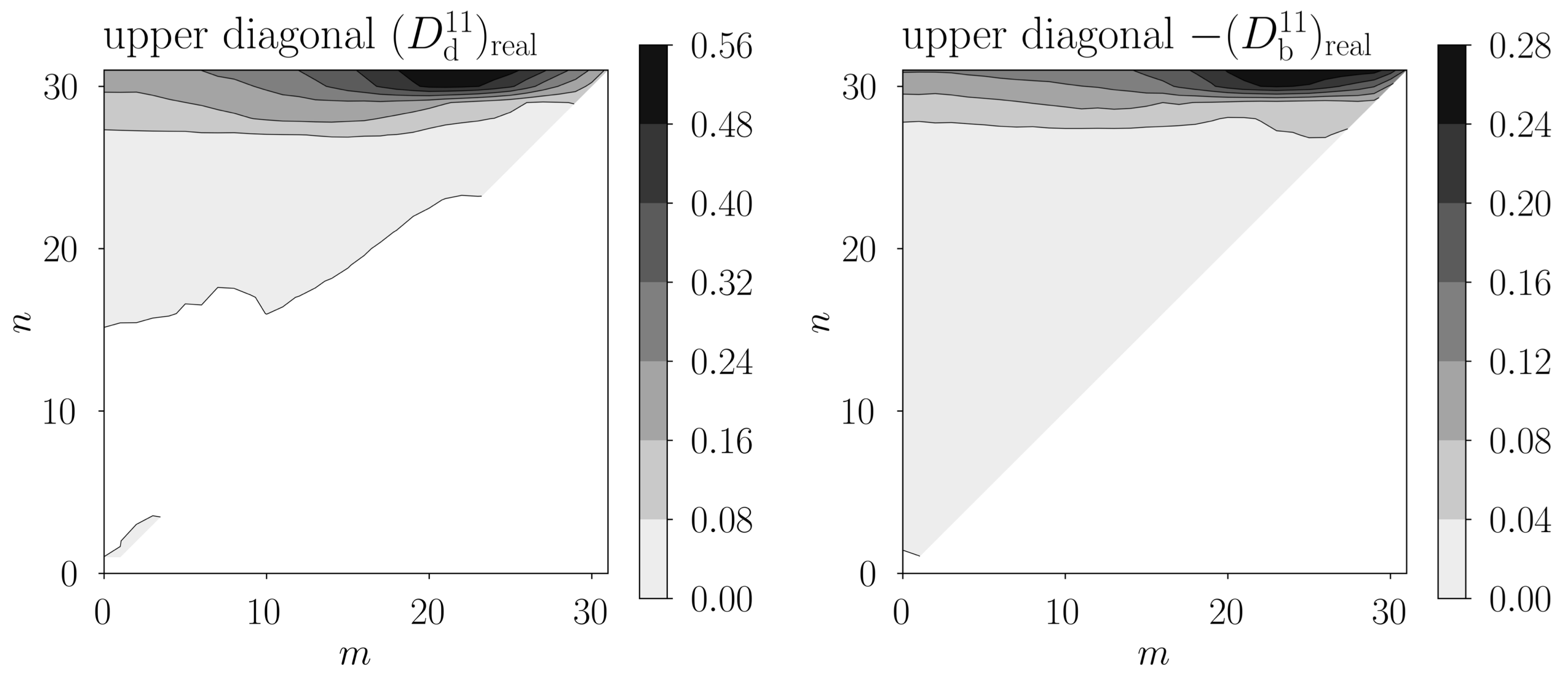


$$\widehat{\boldsymbol{q}}_t^S = -\boldsymbol{D}_{\boldsymbol{d}}\widehat{\boldsymbol{q}} + \widehat{\boldsymbol{f}}$$

Fluctuating Subgrid Tendency - parameterised for each wavenumber pair (m,n) using the method of Frederiksen & Kepert (2006).

$\widehat{\boldsymbol{q}}_t^S$: Eddy-Eddy Interactions

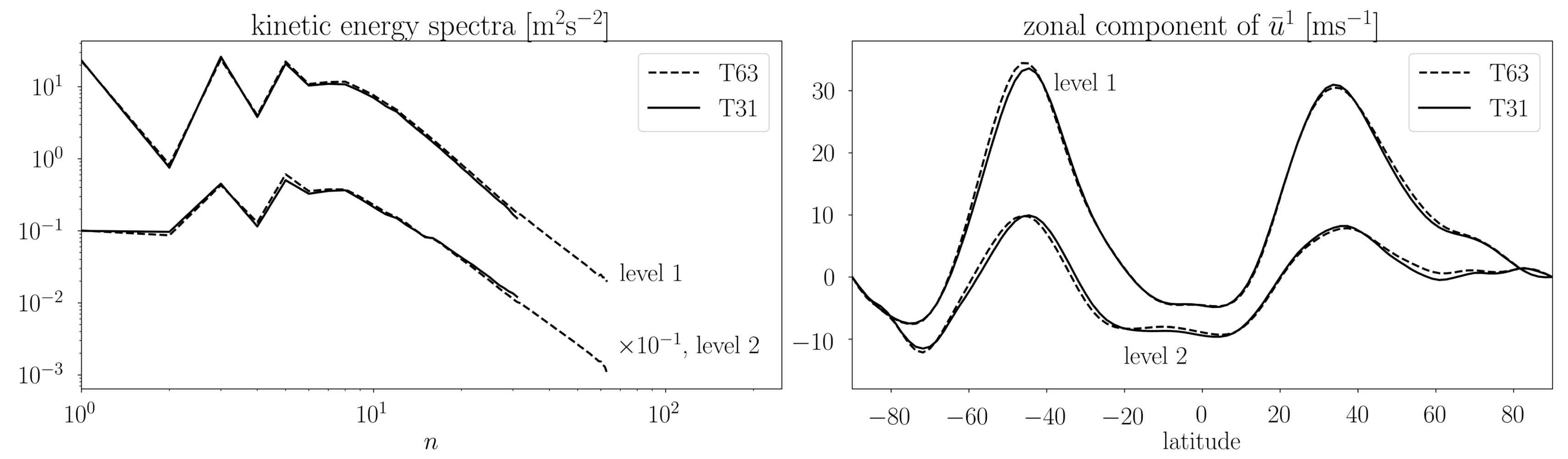
The 2×2 drain matrix ($\boldsymbol{D}_{\boldsymbol{d}}$) acts upon the fluctuating field ($\widehat{\boldsymbol{q}}$) with the 2×1 stochastic backscatter force ($\widehat{\boldsymbol{f}}$) added, of variance proportional to $\boldsymbol{D}_{\boldsymbol{b}}$.


upper diagonal $(D_{\mathrm{d}}^{11})_{\mathrm{real}}$

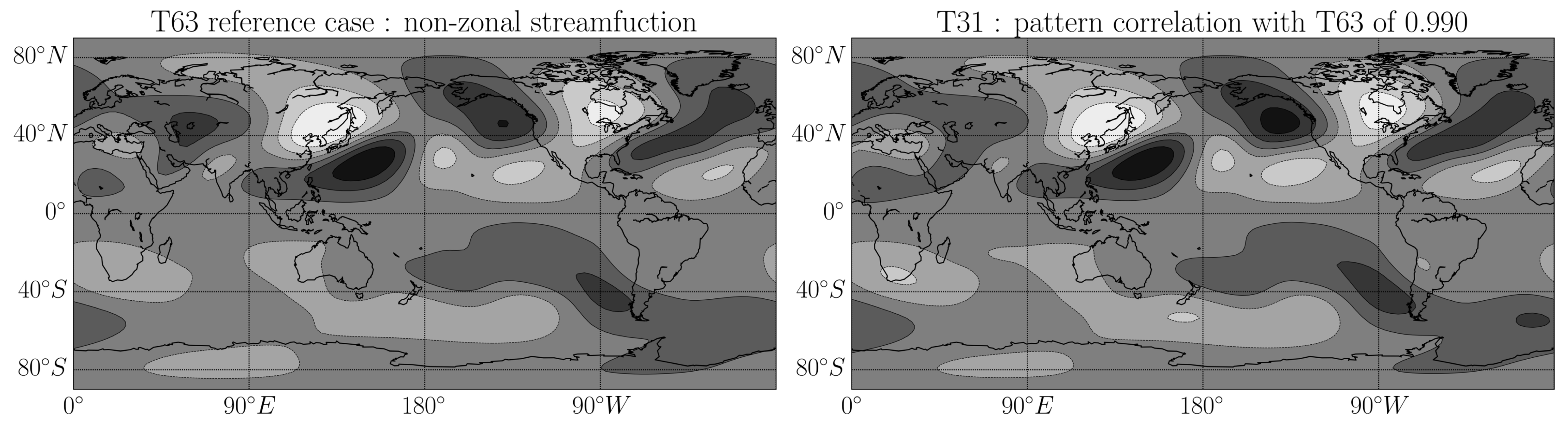
upper diagonal $-(D_{\mathrm{b}}^{11})_{\mathrm{real}}$

Large Eddy Simulation

When all interactions are parameterised T31 shown below to reproduce the kinetic energy spectra, mean jets, and non-zonal streamfuction fields.


kinetic energy spectra $[\mathrm{m^2s^{-2}}]$

zonal component of $\bar{u}^1$ $[\mathrm{ms^{-1}}]$


T63 reference case : non-zonal streamfuction

T31 : pattern correlation with T63 of 0.990

This approach has previously been successfully applied to atmospheric, oceanic and boundary layer flows (Kitsios et. al. 2012,2013,2015,2017).

FOR FURTHER INFORMATION
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